A NEW SUPERFLUID LEAK TIGHT LOW TEMPERATURE VALVE USING A MAGNETOSTRICTIVE ACTUATOR

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AIMTRACT

Low temperature valves play an important role in many research and development applications. Conventional low temperature valves primarily use actuation mechanisms depending on either gas or mechanical pressures. These actuation mechanisms usually require inconvenient operating procedures such as a gas handling system or manual operation. We developed a superfluid leak tight low temperature valve that can be activated by a magnetostrictive material. All that is required to activate this magnetostrictive valve is a magnetic field produced by a simple power supply and coil. This new valve consists of separate valve and actuator units. The valve unit is designed to be normally closed using a spring for better thermal isolation and minimization of the magnetic field effect during an experiment, The stem of the valve is made of a hard 440c stainless steel ball while the seat uses a softer 304 st sinless steel.

INI'RODUCTION

Low temperature valves arc essential to isolate cryogenic gases at low temperatures for various applications, There have been many efforts to develop better techniques to control the valve and the valve material at low temperatures. Recyclable. gas pressure operated. low temperature valves use Teflon/metal or German silver/hardened BeCu as a tip and seat [1].' The former combination requires operating the valve only at low temperatures because of relatively large thermal contract ion of the Teflon. The later combination is found to be leak tight at low temperature, however its life time is in question due to a relatively large difference in the hardness of the materials. Researchers have also used a metal diaphragm and a sharp knife edge metal surface for sealing [2]. In this case a metal diaphragm is pushed against the seat by either gas pressure or mechanical actuator, This kind of valve usually has a short life time because its principle of the operation depends on the deformation of the material. Even more serious problems are associated with the actuation mechanisms of those conventional low temperature valves, Conventional techniques usually require a complicated gas handling system (pneumatic valve) or manual operation (mechanical valve) that are very difficult to control remotely. These actuation mechanisms also involve an additional heat leak to the low temperature environment, A intuitive solution to this problem is to use an electromagnetic force as an actuation mechanism. However, the force required to close the valve at low temperature is too large for the direct usage of the electromagnetic force. A new actuation mechanism that can be controlled remotely and introduces a minimal heat leak to the system is needed to overcome these difficulties.

When a magnetic material is exposed to a magnetic field, its physical dimensions change. This magnetostriction effect was first discovered in nickel by Joule in 1842. Magnetostriction is a result of the rotation of magnetic moments that cause external strains in the substance. These strains result in expansion or contraction of the material in the direction of a magnetic field. The magnetostrictive effect is well described in ref [3]. Although magnetostriction occurs in most magnetic materials, the magnitude of the strain is extremely small ($\delta l/l<10^{-5}$). This limits usage of this novel effect in any application requiring substantial displacements. Recently, a gigantic magnetostriction effect was discovered in an alloy of rare earth compounds

(Tb_xDy_{1-x}) [4]. The size of the strain can be as large as 61/1 -10-2 at low temperatures. Our development of a new low temperature magnetostrictive actuator was motivated by the availability of these gigantic magnetostrictive materials,

PRELIMINARY TEST

Even though this material has been known for a few years, almost no measurements have been performed on this material at liquid helium low temperatures. We have carried out a simple experiment with a single crystal rod of $Tb_{0.76}Dy_{0.24}$ to study the size of the strain as a function of the magnetic field (see ref. [4]). This composition was chosen to have maximum strain at low temperatures, A schematic drawing of the test set up is shown in Fig. 1. A small superconducting solenoid wound with NbTi wire produced the required magnetic field. The induction/current ratio of the magnet was calculated to be 30mT/Amp at the center of the magnet,

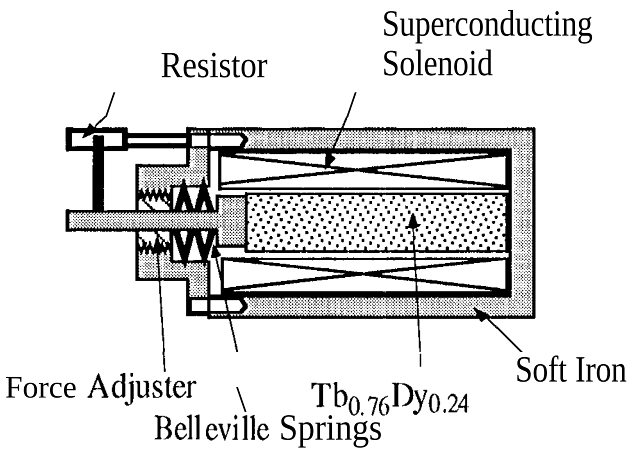

Figure 1. The schematic drawing of preliminary test apparatus.

An external assembly consisting of soft iron served as a flux path and a Bellville spring provided an initial stress of 8 MPa to the sample. A metal film resistor with a point contact on its surface was mounted to detect change in relative position between the sample and the housing. The most important result of this preliminary experiment was that the thermal contraction of the $Tb_{0.76}Dy_{0.24}$ sample relative to the soft iron closure was about a factor of two smaller than the positive strain due to the magnetostriction effect. This experimental observation simplified the design of the actuator for the low temperature valve.

VALVE CONSTRUCTION

The basic strategy in constructing this valve was modularization. The valve consisted of two main bodies that were completely separable. One modular component completely contained the valve mechanism while the other modular component contained the actuator. The schematic drawing of the valve is shown in Fig. 2. The valve was designed to be normally closed. This had several advantages over a normally opened valve. For many scientific applications the thermal heat leak to the system must be minimized. This valve provided near zero heat leak to the system since the superconducting solenoid dissipated zero heat, Also, a magnetic disturbance to other experimental apparatus near the valve due to the actuation will only occur during sample loading time (valve open) when generally no experimental data is being taken. The force required to close the valve was determined experimentally during preliminary tests. Nevertheless, a force adjuster was built in for flexibility. We used about 150 lbs of force to close the valve at low temperatures. A stack of Bellville springs @S 1-3.2-0.5) were used to obtain these high forces. Each of these springs provided 88 lbs of force under compression of 0.020 inch (50% of total travel length). The compression of the springs was made by rotating a 7/16"-28 brass screw. A stainless steel shim stock (302 stainless steel, 0.004" thickness) was used to seal the valve. This had advantages over a typical bellows sealed valve in terms of cleanliness and compactness. Solder joints were eliminated in the valve assembly by E-beam welding the diaphragm to the valve body. The actual seal was made between a stainless steel ball (440c stainless steel, 0.125" diameter) and 304 stainless steel body.

The novel feature of this valve is its actuation mechanism. A single crystal b-axis rod of $Tb_{0.76}Dy_{0.24}$ was grown at the (DoE) Ames Laboratory. It was initially compressed with about 8 MPa of pressure by a similar force adjuster as used in the valve body. The demagnetizing field was substantially reduced by a soft iron closure around the rod and the solenoid. The solenoid was constructed using superconducting NbTi wire. The induction/current ratio at the center of the magnet was roughly calculated to be 40mT/amp.

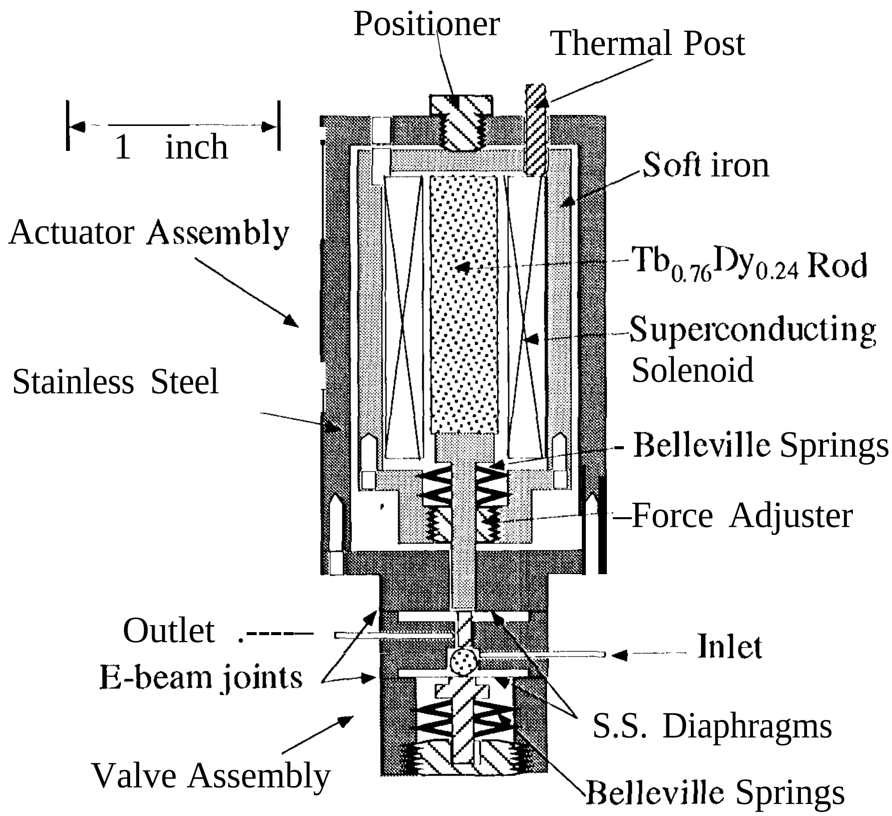

Figure 2 Schematic drawing of the valve assembly.

TEST AND RESULTS

The valve was initially shown to be leak tight (leak rate < 10-10 atm cc/see) at room temperature using less than 30 lbs of force. However, it required about 150 lbs of force to become leak tight in a 4.2 Kelvin liquid helium bath. The force required was obtained simply by rotating a screw type force adjuster at room temperature that compressed the Bellcville springs. The actuation test of the valve was also performed by supplying current to the solenoid, We used helium gas to pressurize one side of the valve while the other side was pumped out using a vacuum pump. The pressure on the pump side was monitored using a pressure gauge. Figure 3 shows the pumping side pressure normalized by the averaged pumping pressure of the fully opened valve as a function of the current through the coil. We opened and closed the valve more than 100 times without noticing any degradation in its performance.

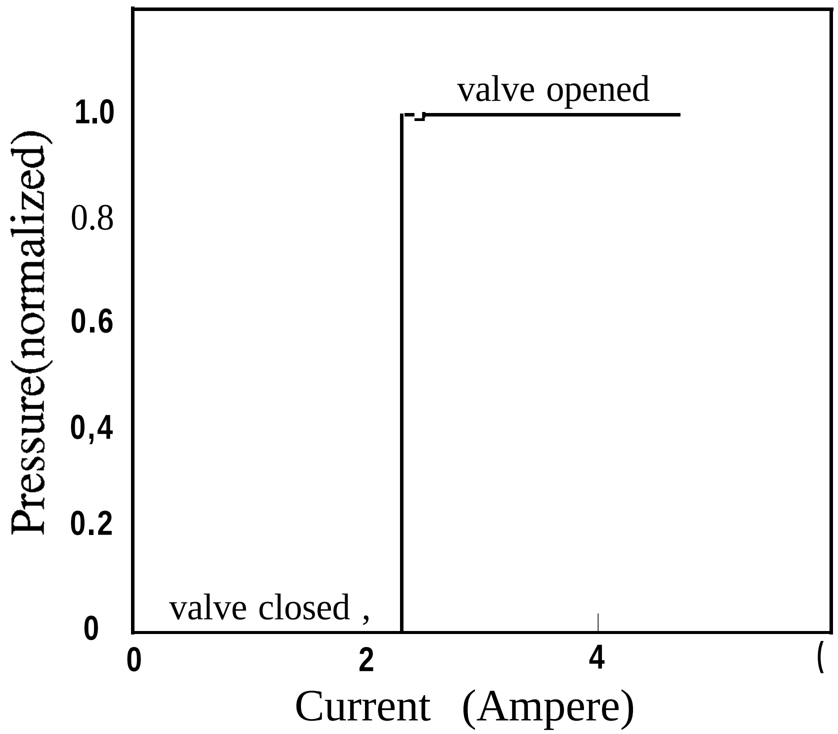

Figure 3. Pumping pressure vs. current through the solenoid. The pressure is normalized to the fully opened valve value.

A second experiment was carried out in a laboratory built cryostat. The cryostat had a helium evaporation cooler inside a vacuum can so that we could cool a He^4 sample down below its superfluid transition temperature. Since the superconducting magnet was operated in a vacuum can, thermal anchoring of the wires was crucial. The current leads of the magnet were thermally anchored to the cooling stages. Outside the vacuum can NbTi current lead wires were spot welded to copper cladded NbTi wires by etching off copper. The copper cladded wires extended up to the room temperature flange of the cryostat. A leak detector was connected to the outlet of the valve to determine whether the valve was superfluid leak tight. The helium fill line attached to the valve inlet was connected to the helium reservoir. A low temperature strain gauge conncctcd to the reservoir monitored small pressure changes of the system after the valve was closed, We monitored the leak rate of the system while helium was condensed inside the reservoir. The observed leak rate was smaller than the maximum sensitivity of the leak detector (=10-l ^{0} atm cc/see). The system was then slowly cooled below the superfluid transition temperature using the Hc^4 evaporation cooler, The leak rate of the valve remained constant at temperatures below 2.0 K.

]n conclusion, we have developed a new liquid helium low temperature valve that can bc activated by a magnetostrictive material driven by a lossless superconducting coil. Wc demonstrated that this valve was leak tight at liquid helium temperatures both above and below the lambda point. We were also able to open the valve at low temperatures by supplying current (-2.3 A) to the superconducting coil.

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REFERENCES

(1) P.R. Roach, J.B. Ketterson, M. Kuchnir: Rev. Sci. Instrum. 43, 898 (1972). T. Tsuda, and Y. Mori, Rev. Sci. Instrum. 62,841 (1991).
(2) Talso Chui [private communication].
(3) B.D. Cullity, "Introduction to magnetic materials" (Addison-Wesley, 1972).
(4) M.L. Spano, A. Ii. Clark, and M. Wun-Fogle, IEEE Trans. on Magnetics 25, 3794 (1 988).